What Caused Japan’s Great Stagnation in the 1990s?*

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Abstract

Despite the widespread belief that Japan’s “Great Stagnation” in the 1990s is due to the financial dysfunction after the collapse of asset price bubbles, Hayashi and Prescott (2002) argue that its main cause is a fall in total factor productivity growth, using a calibrated neoclassical growth model. Our paper fills this gap by estimating a dynamic stochastic general equilibrium model augmented with a financial accelerator mechanism and associated financial shocks. Our estimation results show that even in the presence of the financial shocks an adverse neutral technology shock mainly induced the Great Stagnation and that the estimated neutral technological change is strongly correlated with all enterprises’ financial position in the Tankan. Based on these findings, we argue that an adverse neutral technology shock which is likely to represent a tightening of firms’ financing that induced reduction of R&D investment and misallocation of capital caused the Great Stagnation.

Keywords: Japan’s Great Stagnation in the 1990s; Adverse neutral technology shock; Tightening of firms’ financing; Reduction of R&D investment; Misallocation of capital

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1 Introduction

Despite the widespread belief that Japan’s “Great Stagnation” in the 1990s is due to the dysfunction of the financial system stemming from the collapse of asset price bubbles in the early 1990s, Hayashi and Prescott (2002) argue that its main cause is a fall in total factor productivity (TFP) growth.\(^1\) Indeed, their calibrated neoclassical growth model shows that a sharp decline in the growth rate of TFP accounts well for Japan’s severe economic downturn observed after the bubble burst.\(^2\)

Our paper fills the gap between the widespread belief and Hayashi and Prescott (2002)’s argument regarding the cause of Japan’s Great Stagnation in the 1990s. Specifically, it addresses the questions of what shock is the main cause of the Great Stagnation and what that shock really represents, using an estimated dynamic stochastic general equilibrium (DSGE) model. In this model the financial accelerator mechanism of Bernanke et al. (1999) and associated financial shocks to the external finance (EF) premium and entrepreneurs’ net worth are incorporated to compare the contribution to the Great Stagnation between the two financial shocks and other nine shocks, such as those to the rates of neutral and investment-specific (IS) technological changes, the marginal efficiency of investment (MEI), demand, markups, and monetary policy. The model is estimated using a Bayesian likelihood approach with eleven quarterly time series from Japan: output, consumption, investment, labor, the wage, the consumption price, the investment price, the monetary policy rate, the loan rate, loan, and net worth.

The main results of the paper are twofold. First, even in the presence of the financial shocks to the EF premium and entrepreneurs’ net worth, an adverse neutral technology shock mainly induced Japan’s Great Stagnation in the 1990s, in line with the view of Hayashi and Prescott (2002). The variance decomposition shows that the main driving force of fluctuations in output growth is the neutral technology shock, whereas the financial shocks play a minor role. The historical decomposition demonstrates that the adverse neutral technology shock explains most

\(^1\)For the term “Great Stagnation” and Japan’s economic situation of that time, see Hutchison et al. (2006). Bayoumi (2001) estimates a vector autoregression model to show that the major explanation of Japan’s Great Stagnation in the 1990s is disruption in financial intermediation, largely operating through the impact of changes in domestic asset prices on bank lending.

\(^2\)For Japan’s Great Stagnation in the 1990s, Hayashi and Prescott (2002) also indicate the importance of the 1988 revision of Japan’s Labor Standards Law, which reduced the workweek length (average hours worked per week) from 44 hours to 40 hours between 1988 and 1993.
of the fall in output growth during the Great Stagnation in the 1990s. Second, the time series of the estimated rate of neutral technological change is strongly correlated with that of the diffusion index of all enterprises’ financial position in the Tankan, the Short-term Economic Survey of Enterprises in Japan. Therefore, the adverse neutral technology shock measured during the Great Stagnation in the 1990s can be considered to capture a tightening of firms’ financing that induced reduction of R&D investment and misallocation of capital at that time. Based on these two main results, our paper argues that an adverse neutral technology shock which is likely to represent a tightening of firms’ financing that induced reduction of R&D investment and misallocation of capital caused the Great Stagnation in the 1990s.

The remainder of the paper proceeds as follows. Section 2 describes a DSGE model. Section 3 presents strategy and data for estimating the model. Section 4 explains results of empirical analysis. Section 5 concludes.

2 The DSGE model

The financial accelerator mechanism of Bernanke et al. (1999) has been employed in recent empirical studies on DSGE models, such as Christensen and Dib (2008), De Graeve (2008), Hirose (2008), Christiano et al. (2013), and Kahiatsu and Kurozumi (2013). Our model incorporates this mechanism and associated financial shocks to the EF premium and entrepreneurs’

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3 In an estimated DSGE model where financial frictions and associated financial shocks as well as financial data are absent, Hirose and Kurozumi (2012) obtain a similar result to ours, although their estimated adverse MEI shock plays an important role for the fall in investment growth during the Great Stagnation in the 1990s. Muto et al. (2013) estimate a two-sector DSGE model augmented with the chained credit contracts of Hirakata et al. (2011) and associated financial shocks to net worth of financial intermediaries as well as entrepreneurs, and obtain a similar result to ours, although their estimated financial shocks play a somewhat active role for the fall in output growth during the Great Stagnation in the 1990s.

4 Ogawa (2007) analyzes a panel dataset to show that massive amounts of outstanding debt decreased firms’ R&D investment and hence TFP growth during the Great Stagnation in the 1990s. The empirical results of Nishimura et al. (2005) and Fukao and Kwon (2006) indicate misallocation of resources to inefficient existing firms as the cause of the slowdown in TFP growth during the Great Stagnation in the 1990s. Behind the background of this TFP slowdown, there is the so-called “evergreening” behavior of troubled Japanese banks of that time pointed out by Peek and Rosengren (2005) and Caballero et al. (2008), who all show that these banks had an incentive to allocate credit to severely impaired borrowers (the so-called “zombies”) so as to avoid the realization of losses on their own balance sheets and this induced misallocation of credit during the Great Stagnation in the 1990s.
net worth in the otherwise standard DSGE model of Hirose and Kurozumi (2012), which is similar to the models of Christiano et al. (2005) and Smets and Wouters (2007).

In the model economy there are a representative household that consists of worker and entrepreneur members, financial intermediaries, intermediate-good firms, consumption-good firms, investment-good firms, capital-good firms, and a central bank. Each agent’s behavior is described in turn.

2.1 The representative household

In the representative household there is a continuum of members. Some members are workers \( m \in [0, 1] \) and others are entrepreneurs. As in Andolfatto (1996) and Merz (1995), all members are assumed to pool consumption and make joint consumption-saving decisions, in order to avoid distributional issues. The household derives utility from purchasing consumption goods \( C_t \) and disutility from supplying differentiated labor services \( \{h_t(m)\} = \left\{ \int_0^1 h_t(m, f)df \right\} \) to intermediate-good firms \( f \in [0, 1] \). This household’s preferences are then represented by the utility function

\[
E_t \sum_{t=0}^{\infty} \beta^t \exp(z_t^b) \left[ \frac{(C_t - \theta C_{t-1})^{1-\sigma}}{1-\sigma} - (Z_t^*)^{1-\sigma} \exp(z_t^h) \int_0^1 (h_t(m))^{1+\chi} \frac{1}{1+\chi} dm \right],
\]

where \( E_t \) is the expectation operator conditional on information available in period \( t \), \( \beta \in (0, 1) \) is the subjective discount factor, \( \sigma > 0 \) and \( \theta \in [0, 1] \) are the degrees of relative risk aversion and internal habit persistence in consumption preferences, \( \chi > 0 \) is the inverse of the elasticity of labor supply, and \( z_t^b \) and \( z_t^h \) represent an intertemporal preference shock and a labor supply shock, respectively. As in Erceg et al. (2006), the labor disutility term contains \( (Z_t^*)^{1-\sigma} \), where \( Z_t^* \) is the composite technological level explained later, in order to ensure the existence of a balanced growth path for the model economy. The household’s budget constraint is given by

\[
P_t C_t + D_t = r_t^n D_{t-1} + P_t \int_0^1 W_t(m)h_t(m)dm + T_t,
\]

where \( P_t \) is the price of consumption goods, \( D_t \) is deposits in financial intermediaries, \( r_t^n \) is the gross deposit rate, which is assumed to equal the monetary policy rate, \( W_t(m) \) is worker \( m \)’s real wage, and \( T_t \) consists of profits received from firms and a lump-sum public transfer.
The first-order conditions for optimal decisions on consumption and deposits are given by

\[
\Lambda_t = \exp(z^b_t) (C_t - \theta C_{t-1})^{-\sigma} - \beta \theta E_t \exp(z^b_{t+1}) (C_{t+1} - \theta C_t)^{-\sigma}, \quad (1)
\]

\[
1 = E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} \frac{r^n_t}{\pi_{t+1}}, \quad (2)
\]

where \( \Lambda_t \) is the marginal utility of consumption and \( \pi_t = P_t / P_{t-1} \) is the gross consumption-good price inflation rate.

### 2.1.1 Workers

Under monopolistic competition, intermediate-good firms’ demand for worker \( m \)'s labor services is given by

\[ h_t(m) = h_t(W_t(m)/W_t)^{-\theta^m}, \]

where \( h_t = \left[ \int_0^1 (h_t(m))^{(\theta^m - 1)/\theta^m} \, dm \right]^{\theta^m/(\theta^m - 1)} \) is an aggregate of differentiated labor services with the substitution elasticity \( \theta^m > 1 \) and

\[
W_t = \left[ \int_0^1 (W_t(m))^{1-\theta^m} \, dm \right]^{\frac{1}{1-\theta^m}} \quad \text{(3)}
\]

is the corresponding aggregate real wage. Each wage \( P_t W_t(m) \) is set on a staggered basis à la Calvo (1983). In each period, a fraction \( 1 - \xi_w \in (0, 1) \) of wages is reoptimized, while the remaining fraction \( \xi_w \) is set by indexation to both the gross steady-state balanced growth rate explained later, \( z^* \), and a weighted average of past and steady-state inflation, \( \pi_{t-1} \pi^{1-\gamma_w} \), where \( \gamma_w \in [0, 1] \) is the relative weight on past inflation. Then, each wage reoptimized in period \( t \) is chosen so as to maximize

\[
E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \Lambda_{t+j} h_{t+j|m}(m) \frac{P_t W_t(m)}{P_{t+j} W_{t+j}} \prod_{k=1}^{j} \left( z^w_{t+j} \pi_{t+k-1} \pi^{1-\gamma_w} \right) - \frac{\exp(z^b_{t+j})(Z^*_{t+j})^{-\sigma} \exp(z^b_{t+j}) (h_{t+j|m}(m))^{1+\chi}}{1+\chi} \quad \text{(1)}
\]

subject to

\[
h_{t+j|m}(m) = h_{t+j} \left[ \frac{P_t W_t(m)}{P_{t+j} W_{t+j}} \prod_{k=1}^{j} \left( z^w_{t+k-1} \pi^{1-\gamma_w} \right) \right]^{-\theta^w_{t+j}}.
\]

The first-order condition for the reoptimized real wage \( W^*_t \) is given by

\[
1 = \frac{E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \Lambda_{t+j} W_{t+j} h_{t+j} \left[ W^*_t(z^*)^{j} \prod_{k=1}^{j} \left( \frac{\pi_{t+k-1} \pi^{1-\gamma_w}}{\pi_{t+k}} \right) \right]^{-\theta^w_{t+j}}}{E_t \sum_{j=0}^{\infty} (\beta \xi_w)^j \Lambda_{t+j} W_{t+j} h_{t+j} \left[ W^*_t(z^*)^{j} \prod_{k=1}^{j} \left( \frac{\pi_{t+k-1} \pi^{1-\gamma_w}}{\pi_{t+k}} \right) \right]^{-\theta^w_{t+j}}} \quad \text{(4)}
\]
where $\lambda_t^w \equiv 1/(\theta_t^w - 1) > 0$ denotes the wage markup. The aggregate wage equation (3) can be reduced to

$$1 = (1 - \xi_w) \left( \left( \frac{W_t^o}{W_t} \right)^{-\frac{1}{\lambda_t^w}} + \sum_{j=1}^{\infty} (\xi_w)^j \left\{ \left( \frac{(z^*)^j W_t^o}{W_t} \prod_{k=1}^{j} \left[ \left( \frac{\pi_{t-k}}{\pi} \right)^{\gamma_w \pi} \right] \right)^{-\frac{1}{\lambda_t^w}} \right\} \right).$$ (5)

### 2.1.2 Entrepreneurs and financial intermediaries

Entrepreneurs adjust the utilization rate $u_t$ on capital $K_{t-1}$ that was purchased at the real price $Q_{t-1}$ from capital-good firms at the end of the previous period $t - 1$, and provide capital services $u_t K_{t-1}$ at the real rental rate $R^k_t$ for intermediate-good firms. After intermediate-good firms’ production, capital is depreciated at the rate $\delta(u_t)$. As in Greenwood et al. (1988), it is assumed that a higher utilization rate of capital leads to a higher depreciation rate of capital. The depreciation rate function $\delta(\cdot)$ thus has properties of $\delta' > 0$, $\delta'' > 0$, $\delta(1) = \delta \in (0,1)$, and $\delta'(1)/\delta''(1) = \tau > 0$. Then, entrepreneurs sell the resulting capital $(1 - \delta(u_t))K_{t-1}$ to capital-good firms at the real price $Q_t$. The first-order condition for optimal decisions on the capital utilization rate is given by

$$R^k_t = Q_t \delta'(u_t).$$ (6)

Entrepreneurs’ purchase of capital at the end of each period is financed by their real net worth $N_t$ and by their real loan

$$L_t = Q_t K_t - N_t$$ (7)

from financial intermediaries at the gross (nominal) loan rate $r^l_t$. The first-order condition for optimal decisions on the purchase of capital is given by

$$E_t \Lambda_{t+1} x_{t+1} = E_t \Lambda_{t+1} \frac{r^l_t}{\pi_{t+1}},$$ (8)

where $x_t$ is the ex-post marginal return on capital given by

$$x_t = \frac{u_t R^k_t + Q_t (1 - \delta(u_t))}{Q_{t-1}}.$$ (9)

The loan rate consists of the deposit rate $r^d_t$ and the EF premium $ef p_t$,

$$r^l_t = r^d_t ef p_t = r^d_t F \left( \frac{Q_t K_t}{N_t} \right) \exp(z^e_t),$$ (10)

where the EF premium function $F(\cdot)$ depends on entrepreneurs’ leverage ratio $Q_t K_t/N_t$ and satisfies $F' > 0$ and $\mu = (QK/N)F'(QK/N)/F(QK/N) \geq 0$ as in empirical studies on DSGE.
models with the Bernanke et al. (1999) financial accelerator mechanism, such as Christensen and Dib (2008), De Graeve (2008), Hirose (2008), and Kihatsu and Kurozumi (2013), and where \( z_t^\mu \) denotes a shock to the EF premium. This shock represents a disturbance to the financial sector that boosts the EF premium beyond the level warranted by currently available information about the state of the economy.

After selling capital to capital-good firms and paying back the loan \( r_{l-1}^l P_{l-1} L_{l-1} \) to financial intermediaries, a fraction \( 1 - \eta_t \in (0, 1) \) of entrepreneurs becomes workers, while the remaining fraction \( \eta_t \) survives until the next period.\(^5\) Entrepreneurs’ real net worth then evolves according to

\[
N_t = \eta_t \left( x_t Q_{l-1} K_{l-1} - \frac{r_{l-1}^l L_{l-1}}{r_t} \right) + (1 - \eta_t) \omega Z_t^*,
\]

where \( \omega \) is a positive constant. The term \( \omega Z_t^* \) denotes the transfer that surviving entrepreneurs receive from entrepreneurs who become workers. The probability of surviving until the next period is given by

\[
\eta_t = \eta \exp(z_t^\beta) / (1 - \eta + \eta \exp(z_t^\beta)),
\]

where \( z_t^\beta \) is a disturbance to this probability and represents a net worth shock.

### 2.2 Intermediate-good firms

Each intermediate-good firm \( f \in [0, 1] \) produces output \( Y_t(f) \) by choosing a pair of labor and capital inputs \( \{h_t(f), K_t(f)\} \) at the real rental rates \( \{W_t, R_t^m\} \) according to the production function

\[
Y_t(f) = \left( Z_t h_t(f) \right)^{1-\alpha} (K_t(f))^\alpha - \phi y Z_t^*,
\]

Here, \( Z_t \) represents the level of neutral technology and its logarithm is assumed to follow the stochastic process

\[
\log Z_t = \log z + \log Z_{t-1} + z_t^\gamma,
\]

where \( z > 1 \) denotes the gross steady-state rate of neutral technological change and \( z_t^\gamma \) represents a (non-stationary) neutral technology shock. The labor input is given by

\[
h_t(f) = \left[ \int_0^1 (h_t(m, f))^{\theta_t^m - 1} \theta_t^m \ dm \right]^{\theta_t^e / (\theta_t^m - 1)}
\]

and \( \alpha \in (0, 1) \) represents the capital elasticity of output. The last term in the production function (12), \( -\phi y Z_t^* \), is the fixed cost of producing output. Here, \( \phi \in [0, 1) \), \( y \) is the steady-state value of detrended output \( y_t = Y_t/Z_t^* \), and \( Z_t^* \) is the composite technological level given by

\[
Z_t^* = Z_t (\Psi_t)^{\alpha / (1 - \alpha)},
\]

where \( \Psi_t \) represents the level of IS

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\(^5\)This assumption ensures that entrepreneurs’ net worth will never be sufficient to entirely finance their purchase of capital.
technology explained later. This composite technological level can be derived using the Cobb-Douglas production function (12). Then, the composite technological change \( Z_t^*/Z_{t-1}^* \) turns out to be the gross rate of balanced growth and its steady-state rate is given by \( z^* = z \psi^{\alpha/(1-\alpha)} \), where \( \psi > 1 \) is the gross steady-state rate of IS technological change.

Combining first-order conditions for optimal decisions on labor and capital inputs leads to

\[
\frac{1 - \alpha}{\alpha} = \frac{W_t h_t}{R^k_t u_t K_{t-1}},
\]

where \( h_t = \int_0^1 h_t(f) df \) and \( u_t K_{t-1} = \int_0^1 K_t(f) df \), and the real marginal cost is given by

\[
m_{ct} = \left( \frac{W_t}{(1-\alpha)Z_t} \right)^{1-\alpha} \left( \frac{R^k_t}{\alpha} \right)\alpha.
\]

Under monopolistic competition, intermediate-good firm \( f \) faces consumption-good firms’ demand \( Y_t(f) = Y_t(P_t(f)/P_t)^{-\theta^p_t} \), where \( Y_t \) is consumption-good firms’ output, \( P_t(f) \) is the price of differentiated goods produced by intermediate-good firm \( f \), and \( \theta^p_t > 1 \) is the elasticity of substitution between intermediate goods. Then, intermediate-good firms set prices of their differentiated products on a staggered basis à la Calvo (1983). In each period, a fraction \( 1 - \xi_p \in (0, 1) \) of intermediate-good firms reoptimizes prices, while the remaining fraction \( \xi_p \) indexes prices to a weighted average of past and steady-state inflation \( \pi_{t-1}^{\gamma_p} \pi^{1-\gamma_p} \), where \( \gamma_p \in [0, 1] \) is the relative weight on past inflation. Hence, intermediate-good firms that reoptimize prices in the current period choose their prices so as to maximize

\[
E_t \sum_{j=0}^\infty \xi_p^j \left( \frac{\beta^j \Lambda_{t+j}}{\Lambda_t} \right) \left[ \frac{P_t(f)}{P_{t+j}} \prod_{k=1}^j \left( \frac{\pi_{t+k-1}^{\gamma_p} \pi^{1-\gamma_p}}{\pi_{t+k}^{\gamma_p}} \right) - m_{ct+j} \right] Y_{t+j|t}(f)
\]

subject to

\[
Y_{t+j|t}(f) = Y_{t+j} \left[ \frac{P_t(f)}{P_{t+j}} \prod_{k=1}^j \left( \frac{\pi_{t+k-1}^{\gamma_p} \pi^{1-\gamma_p}}{\pi_{t+k}^{\gamma_p}} \right) \right]^{-\theta^p_{t+j}},
\]

where \( \beta^j \Lambda_{t+j}/\Lambda_t \) shows the stochastic discount factor between period \( t \) and period \( t + j \). The first-order condition for the reoptimized price \( P^p_t \) is given by

\[
1 = \frac{E_t \sum_{j=0}^\infty (\beta \xi_p)^j \left( 1 + \lambda^p_{t+j} \right) \frac{m_{ct+j} \Lambda_{t+j} Y_{t+j}}{\Lambda^p_{t+j}} \left\{ \frac{P^p_t}{P_t} \prod_{k=1}^j \left( \frac{\pi_{t+k-1}^{\gamma_p} \pi^{1-\gamma_p}}{\pi_{t+k}^{\gamma_p}} \right) \right\}^{\frac{1 + \lambda^p_{t+j}}{\lambda^p_{t+j}}} \left[ \frac{\Lambda^p_{t+j}}{\Lambda_{t+j}} \right]^{-\lambda^p_{t+j}}}{E_t \sum_{j=0}^\infty (\beta \xi_p)^j \left( \frac{\Lambda_{t+j} Y_{t+j}}{\Lambda^p_{t+j}} \right) \left\{ \frac{P^p_t}{P_t} \prod_{k=1}^j \left( \frac{\pi_{t+k-1}^{\gamma_p} \pi^{1-\gamma_p}}{\pi_{t+k}^{\gamma_p}} \right) \right\}^{\frac{1 + \lambda^p_{t+j}}{\lambda^p_{t+j}}} \left[ \frac{\Lambda^p_{t+j}}{\Lambda_{t+j}} \right]^{-\lambda^p_{t+j}}},
\]

where \( \lambda^p_t \equiv 1/(\theta^p_t - 1) > 0 \) denotes the intermediate-good price markup.

\[\text{6} \]The value of \( \phi \) is chosen so that intermediate-good firms’ profits are zero in the steady state.
2.3 Consumption-good firms

Consumption-good firms produce output \( Y_t \) by choosing a combination of intermediate goods \( \{Y_t(f)\} \) so as to maximize profit \( P_t Y_t - \int_0^1 P_t(f)Y_t(f)df \) subject to the production technology \( Y_t = (\int_0^1 Y_t(f)^{(\theta^p - 1)/\theta^p} df)^{\theta^p/(\theta^p - 1)} \). The first-order condition for profit maximization yields consumption-good firms’ demand for intermediate good \( f \) given by \( Y_t(f) = Y_t(P_t(f)/P_t)^{-\theta^p} \), as mentioned above.

Perfect competition in the consumption-good market leads to the price \( P_t \) given by

\[
P_t = \left( \int_0^1 P_t(f)^{1-\theta^p} df \right)^{1/\theta^p}.
\]

From the Calvo-style staggered price-setting of intermediate-good firms, this equation can be reduced to

\[
1 = (1 - \xi_p) \left( \left( \frac{P^o}{P_t} \right)^{-\frac{1}{\theta^p}} + \sum_{j=1}^{\infty} (\xi_p)^j \left\{ \left( \frac{P^o}{P_t} \right)^{\frac{1}{\theta^p}} \prod_{k=1}^{j} \left[ \left( \frac{\pi_{t-k}}{\pi} \right)^{\gamma_p} \frac{\pi}{\pi_{t-k+1}} \right] \right\} \right)^{\frac{1}{\theta^p}}.
\]

Aggregating the production function (12) over intermediate-good firms yields

\[
Y_t d_t = (Z_t h_t)^{1-\alpha} (u_t K_{t-1})^{\alpha} - \phi^\gamma Z_t^*,
\]

where \( d_t = \int_0^1 (P_t(f)/P_t)^{-\theta^p} df \) is intermediate-good price dispersion. Note that this dispersion is of second order under the staggered price-setting and that its steady-state value is unity.

2.4 Investment-good firms

Each investment-good firm \( f_i \in [0, 1] \) uses the production technology that converts one unit of consumption goods into \( \Psi_t \) units of differentiated investment goods.\(^7\) Thus, \( \Psi_t \) represents the level of IS technology. Its logarithm is assumed to follow the stochastic process

\[
\log \Psi_t = \log \psi + \log \Psi_{t-1} + z^\psi_t,
\]

\(^7\)Our model contains investment-good firms to introduce IS technological change, since a downward trend is observed in the data on the relative price of investment to consumption. This data is thus indispensable to the estimation of the trend in IS technological change, which is a decisive factor for the trend in investment. Besides, the absence of the data may potentially contaminate the estimates of financial shocks, since these shocks are related through the financial accelerator mechanism to the business cycle component of the data on investment, which is determined by an estimated trend in investment.
where $z_t^\psi$ represents a (non-stationary) IS technology shock. The cost minimization of investment-good firms shows that their real marginal cost equals the inverse of the IS technological level, $1/\Psi_t$. Hence the marginal cost is identical among investment-good firms.

Under monopolistic competition, investment-good firm $f_i$ faces capital-good firms’ demand

$$I_t(f_i) = I_t \left( \frac{P^i_t(f_i)}{P_t} \right)^{-\theta^i_t}, \quad (20)$$

where $P^i_t(f_i)$ is the price of investment goods produced by firm $f_i$, $I_t = \int_0^1 I_t(f_i)^{(\theta^i_t - 1)}/\theta^i_t df_i$ is an aggregate of differentiated investment goods with the substitution elasticity $\theta^i_t > 1$, and

$$P^i_t = \left( \int_0^1 P^i_t(f_i)^{1-\theta^i_t} df_i \right)^{\frac{1}{1-\theta^i_t}} \quad (21)$$

is the corresponding aggregate price of investment goods. Then, investment-good firm $f_i$ sets its price $P^i_t(f_i)$ so as to maximize profit $(P^i_t(f_i)/P_t - 1/\Psi_t) I_t(f_i)$. The first-order condition for profit maximization yields the price given by $P^i_t(f_i) = (1 + \lambda^i_t) P_t/\Psi_t$, where $\lambda^i_t \equiv 1/(\theta^i_t - 1) > 0$ is the investment-good price markup over marginal cost $P_t/\Psi_t$. Then, (21) yields

$$P^i_t = (1 + \lambda^i_t) P_t/\Psi_t = P^i_t(f_i). \quad (22)$$

Moreover, combining this equation and (20) implies that $I_t(f_i) = I_t$. Hence, the price and output are identical among investment-good firms. From (22), the gross rate of change in the relative price of investment goods to consumption goods is given by

$$r^i_t = \frac{P^i_t/P_t}{P^i_{t-1}/P^i_{t-1}} = \frac{1 + \lambda^i_t}{1 + \lambda^i_{t-1}} \frac{\Psi_{t-1}}{\Psi_t}. \quad (23)$$

The market clearing condition for consumption goods is now given by

$$Y_t = C_t + \int_0^1 \frac{I_t(f_i)}{\Psi_t} df_i + g Z^*_t \exp(\tilde{z}_t^\psi) = C_t + \frac{I_t}{\Psi_t} + g Z^*_t \exp(\tilde{z}_t^\psi), \quad (24)$$

where the second equality follows from $I_t(f_i) = I_t$, the last term $g Z^*_t \exp(\tilde{z}_t^\psi)$ denotes demand for consumption goods other than the household’s consumption demand and investment-good firms’ demand, and $\tilde{z}_t^\psi$ represents a shock to this exogenous consumption-demand good.

---

8 If the investment-good markets are perfectly competitive, we have $\lambda^i_t = 0$ in each period $t$, and hence (22) becomes $P^i_t/P_t = 1/\Psi_t$. That is, the inverse of the IS technological level must equal the relative price of investment. Then, since (19) and (23) imply that $r^i_t = 1/(\psi \exp(z^\psi_t))$, the IS technology shock $z^\psi_t$ is completely pinned down by the data on the gross rate of change in the relative price of investment $r^i_t$. In contrast to this restrictive specification, our specification (23), which can be rewritten as $r^i_t = [(1 + \lambda^i_t)/(1 + \lambda^i_{t-1})]/(\psi \exp(z^\psi_t))$, shows that our model allows shocks to the investment-good price markup $\lambda^i_t$ to generate a wedge between $z^\psi_t$ and $r^i_t$. As a consequence, the IS technology shock is identified not only by the data on the relative price of investment but also by other data used in estimation.
2.5 Capital-good firms

Capital-good firms purchase capital goods \((1-\delta(u_t))K_{t-1}\) back from entrepreneurs and make an investment \(I_t = \left(\int_0^1 I_t(f_i)\theta_{t-1}/\theta_{t} df_i\right)^{\theta_{t-1}/\theta_{t}}\) by purchasing a combination of investment goods \(\{I_t(f_i)\}\). As in Justiniano et al. (2010, 2011), this investment is subject to not only adjustment costs \(S\left((I_t/I_{t-1})/(z^*\psi)\right) = (\zeta/2)((I_t/I_{t-1})/(z^*\psi) - 1)^2\), \(\zeta > 0\), advocated by Christiano et al. (2005), but also a shock to the MEI proposed by Greenwood et al. (1988) and denoted by \(z_t^\prime\). This shock represents a technology shock that affects the transformation of investment goods into capital goods. The capital accumulation equation is thus given by

\[
K_t = (1 - \delta(u_t))K_{t-1} + \exp(\left(1 - S\left(z_t^\prime \right)\right) I_t.
\]  

(25)

Then, capital-good firms sell capital \(K_t\) to entrepreneurs.

Capital-good firms’ problem is to choose investment \(I_t\) and a combination of investment goods \(\{I_t(f_i)\}\) so as to maximize profit

\[
E_t \sum_{j=0}^{\infty} \beta^j \frac{\Lambda_{t+j}}{\Lambda_t} \left\{ Q_{t+j} [K_{t+j} - (1 - \delta(u_{t+j}))K_{t+j-1}] - \frac{P_{t+j}^i}{P_t} I_{t+j} \right\}
\]

subject to the capital accumulation equation (25). The first-order condition for optimal decisions on investment \(I_t\) is given by

\[
\frac{P_{t}^i}{P_t} = Q_t \exp(z_t^\prime) \left[1 - \frac{\left(I_t/I_{t-1}\right)}{z^*\psi} - S\left(\frac{\left(I_t/I_{t-1}\right)}{z^*\psi}\right)\right] + E_t \beta \frac{\Lambda_{t+1}}{\Lambda_t} z^*\psi Q_{t+1} \exp(z_{t+1}^\prime) S\left(\frac{\left(I_{t+1}/I_t\right)}{z^*\psi}\right)
\]

(26)

and the one for the cost-minimizing combination of investment goods yields capital-good firms’ demand for firm \(f_i\)’s investment goods given by \(I_t(f_i) = I_t(P_t(f_i)/P_t)^{-\theta_i}\), as mentioned above.

2.6 Central bank

The central bank conducts monetary policy by adjusting the policy rate according to the Taylor (1993) type rule

\[
\log r_t^n = \phi_r \log r_{t-1}^n + (1 - \phi_r) \left(\log r^n + \phi\sum_{j=0}^{3} \frac{\log \pi_{t-j}}{\pi} + \phi_y \log \frac{Y_t/Z_t^*}{y} + \phi_{\Delta y} \log \frac{Y_t/Y_{t-1}}{z^*} + z_t^\prime\right)
\]

(27)

where \(r^n\) is the gross steady-state policy rate, \(\phi_r \in [0,1]\) represents the degree of policy rate smoothing, \(\phi, \phi_y, \phi_{\Delta y} \geq 0\) represent the degrees of policy responses to inflation, output, and output growth, and the disturbance \(z_t^\prime\) represents a monetary policy shock.
### 2.7 Equilibrium conditions

In the model the equilibrium conditions are given by (1), (2), (4)–(9), (14)–(18), (22), (24)–(27), together with the stochastic processes of neutral and IS technological changes, (13), (19), and those of eleven exogenous shocks $z^x_t$, $x \in \{b, g, w, p, i, r, z, \psi, \nu, \mu, \eta\}$, where $z^p_t = (g/y)z^p_t$, $z^w_t$ is a composite shock relevant to the labor disutility disturbance $z^h_t$ and the wage markup $\lambda^w_t$, $z^p_t$ and $z^i_t$ are shocks associated with the intermediate-good price markup $\lambda^i_t$ and the investment-good price markup $\lambda^i_t$, and $z^n_t = (r^F/z^* - 1)z^n_t$. Each of the exogenous shocks is assumed to follow the univariate stationary first-order autoregressive process

$$z^x_t = \rho_x z^x_{t-1} + \varepsilon^x_t, \quad \varepsilon^x_t \sim \text{i.i.d. } N(0, \sigma^2_x), \quad x \in \{b, g, w, p, i, r, z, \psi, \nu, \mu, \eta\},$$

where $\rho_x \in [0, 1)$ is the persistence parameter of the shock $z^x_t$ and $\sigma_x \geq 0$ is the standard deviation of the shock innovation $\varepsilon^x_t$.

### 3 The strategy and data for estimation

This section describes strategy and data for estimating the model presented in the preceding section.

#### 3.1 The estimation strategy

The model is estimated using a Bayesian likelihood approach with eleven quarterly time series from Japan: output $Y_t$, consumption $C_t$, investment $I_t$, labor (hours worked) $h_t$, the real wage $W_t$, the price of consumption goods $P_t$, the relative price of investment goods $P^i_t/P_t$, the monetary policy rate $r^m_t$, the loan rate $r^l_t$, real loan $L_t$, and real net worth $N_t$.

For estimation, the equilibrium conditions presented in the preceding section are rewritten in terms of detrended variables: $y_t = Y_t/Z^*_t$, $c_t = C_t/Z^*_t$, $w_t = W_t/Z^*_t$, $\lambda_t = \Lambda_t(Z^*_t)^\infty$, $i_t = I_t/(Z^*_t \Psi_t)$, $k_t = K_t/(Z^*_t \Psi_t)$, $r^k_t = R^k_t \Psi_t$, $q_t = Q_t \Psi_t$, $n_t = N_t/Z^*_t$, and $l_t = L_t/Z^*_t$. The resulting equilibrium conditions are then log-linearized around a deterministic steady state with the capital utilization rate of unity. The log-linearized equilibrium conditions and steady-state conditions used in estimation are presented in Appendix.

Like recent studies that estimate DSGE models by Bayesian methods, such as Smets and Wouters (2007) and Christiano et al. (2013), we use the Kalman filter to evaluate the likelihood function for the system of log-linearized equilibrium conditions in terms of detrended variables,
and apply the Metropolis-Hastings algorithm to generate draws from the posterior distribution of model parameters.\textsuperscript{9} Based on these draws, we conduct empirical analysis.

3.2 The data

The data on the consumption-good price $P_t$ is the CPI (excluding fresh foods). Then, the data on the relative price of investment $P^i_t/P_t$, output $Y_t$, and consumption $C_t$ are given by dividing the investment deflator, nominal GDP, and nominal consumption with the CPI. The data on investment $I_t$, labor $h_t$, the real wage $W_t$, and the monetary policy rate $r^m_t$ are the same as those in Sugo and Ueda (2008), except that these series are not detrended. The data on the loan rate $r^l_t$ is the average interest rate on contracted loans and discounts, while those on real net worth $N_t$ and real loan $L_t$ are the equity and the sum of non-financial corporations' loans and securities other than shares in Japan’s Flow of Funds Statistics, deflated with the CPI. The corresponding observation equations are

$$
\begin{align*}
100\Delta \log Y_t & \quad \rightarrow \quad z^x
100\Delta \log C_t & \quad \rightarrow \quad z^x
100\Delta \log I_t & \quad \rightarrow \quad z^x + \psi
100\Delta \log h_t & \quad \rightarrow \quad \bar{h}
100\Delta \log W_t & \quad \rightarrow \quad \bar{\pi}
100\Delta \log P_t & \quad \rightarrow \quad \bar{r}^m
100\Delta \log (P^i_t/P_t) & \quad \rightarrow \quad -\bar{\psi}
100\log r^m_t & \quad \rightarrow \quad \bar{r}^m
100\Delta \log h_t & \quad \rightarrow \quad \bar{h}
100\Delta \log r^l_t & \quad \rightarrow \quad \bar{r}^l
100\Delta \log N_t & \quad \rightarrow \quad \bar{z}^x
100\Delta \log L_t & \quad \rightarrow \quad \bar{z}^x
\end{align*}
$$

where $z^x = 100(z^x - 1)$, $\bar{\psi} = 100(\psi - 1)$, $\bar{\pi} = 100(\pi - 1)$, $\bar{r}^m = 100(r^m - 1)$, $\bar{r}^l = 100(r^l - 1)$, $\bar{h}$ is normalized to be equal to zero like Smets and Wouters (2007), and hatted variables represent log-deviations from steady-state values.

The sample period is from 1981:1Q to 1998:4Q. The end of this sample period follows

\textsuperscript{9}Our estimation is done using DYNARE (Adjemian et al., 2011). In each estimation, 200,000 draws were generated and the first half of these draws was discarded. The scale factor for the jumping distribution in the Metropolis-Hastings algorithm was adjusted so that an acceptance rate of around 24\% was obtained.
from the fact that our estimation strategy is not able to take into account the non-linearity in monetary policy rules that stems from the zero lower bound on the monetary policy rate.

3.3 Fixed parameters and prior distributions

Most of the model parameters are estimated, while some are fixed to avoid identification issues. The steady-state output ratio of spending other than consumption and investment is set at the sample mean \( g/y = 0.29 \). The depreciation rate and the wage markup at the steady state are chosen from Sugo and Ueda (2008) (i.e., \( \delta = 0.015 \), \( \lambda^w = 0.2 \)) and the steady-state investment-good price markup is set at \( \lambda^i = 0.2 \).

The prior distributions of parameters are shown in the third to fifth columns of Table 1. For the structural parameters \( \sigma, \theta, \chi, \zeta, \phi, \gamma_w, \xi_w, \gamma_p, \) and \( \xi_p \), the prior distributions are the same as those in Sugo and Ueda (2008). For the monetary policy parameters \( \phi_r, \phi_p, \) and \( \phi_y \), the prior distributions are the same as those in Iiboshi et al. (2006). The prior distributions of the capital elasticity of output \( \alpha \) and the monetary policy response to output growth \( \phi_{\Delta y} \) are the same as those in Smets and Wouters (2007). For the inverse of the elasticity of adjustment cost of the capital utilization rate \( \tau \), the prior distribution is set to be the Gamma distribution with the mean of 0.22 and the standard deviation of 0.1, based on Khan and Tsoukalas (2011). As for the parameters related to the financial accelerator mechanism, the prior distributions of the steady-state survival probability \( \eta \), the steady-state net worth to capital ratio \( n/k \), and the elasticity of the EF premium \( \mu \) are the same as those in Hirose (2008). Regarding the steady-state values of the balanced growth rate, the rate of IS technological change, the inflation rate, the monetary policy rate, and the loan rate (i.e., \( \bar{z}, \bar{\psi}, \bar{\pi}, \bar{\rho}, \bar{r} \)), the prior distributions are set to be the Gamma distributions with the standard deviation of 0.1 and the mean given by the sample mean of the output growth rate, the rate of decline in the relative price of investment, the inflation rate, the monetary policy rate, and the loan rate, respectively. The prior distribution of the normalized steady-state labor \( \bar{h} \) is the same as that in Smets and Wouters (2007). For the parameters of shocks, the Beta distribution with the mean of 0.5 and the standard deviation of 0.2 is chosen for the persistence of each shock (i.e., \( \rho_x, x \in \{b, g, w, p, i, r, z, \psi, \nu, \mu, \eta\} \)) and the Inverse Gamma distribution with the mean of 0.5 and the standard deviation of an infinity is set for the standard deviation of each shock innovation (i.e., \( \sigma_x, x \in \{b, g, w, p, i, r, z, \psi, \nu, \mu, \eta\} \)).
4 Results of the empirical analysis

This section presents results of our empirical analysis. First, estimates of model parameters and cross-correlations of observable variables are explained. Then, variance and historical decompositions of key observable variables and impulse response to key shocks are examined.

4.1 Parameter estimates and cross-correlations

Each parameter’s posterior mean and 90% posterior interval are reported in the last two columns of Table 1. Most of the parameter estimates are similar to those in Hirose and Kurozumi (2012), since our model extends theirs by introducing the financial accelerator mechanism of Bernanke et al. (1999) and associated financial shocks to the EF premium and entrepreneurs’ net worth. Some differences are detected in the elasticity of investment adjustment cost and the inverse of the elasticity of capital utilization rate adjustment cost between our estimates of $\zeta = 0.43$ and $\tau = 0.48$ and their estimates of $\zeta = 7.12$ and $\tau = 2.08$, which implies that the roles of investment adjustment cost and variable capital utilization are minor in our estimated model. These differences arise due to not only the presence of the financial accelerator mechanism in our model but also the presence of the financial data on the loan rate, loan, and net worth in our dataset. In terms of the fit of our model to all the data used in our estimation, the financial accelerator mechanism is a better specification than the investment adjustment cost and variable capital utilization.

To see how well the model fits the data, the cross-correlations of output growth with observable variables in the data and the model are presented in Table 2. This table shows that the model reasonably well captures the cross-correlations in the data. Moreover, the model generates the observed positive comovement of output growth ($\Delta \log Y_t$) with consumption growth ($\Delta \log C_t$), investment growth ($\Delta \log I_t$), labor ($\log h_t$), real wage growth ($\Delta \log W_t$), the monetary policy rate ($\log r^m_t$), the loan rate ($\log r_l^f$), and real loan growth ($\Delta \log L_t$) and the observed negative comovement of output growth with consumption price inflation ($\Delta \log P_t$).

4.2 What shock is the main cause of Japan’s Great Stagnation in the 1990s?

This subsection examines our first question of what shock is the main cause of Japan’s Great Stagnation in the 1990s in our estimated model.

We begin with variance decompositions. Table 3 reports the relative contribution of each
shock to the variances of output growth, consumption growth, investment growth, and labor at the business cycle frequency of 8–32 quarters, evaluated at the posterior mean estimates of parameters. In this table, it is evident that the main source of fluctuations in output growth is the neutral technology shock. This shock explains around two thirds of the fluctuations. The other ten shocks play a minor role. Particularly, the two financial shocks—the EF premium shock and the net worth shock—account for less than two percent of the fluctuations. Moreover, the neutral technology shock is the primary source of fluctuations in consumption growth and investment growth and the second source of fluctuations in labor. Therefore, the neutral technology shock is the main source of Japan’s business cycle fluctuations.

We turn next to historical decompositions. Fig. 1 illustrates the historical decomposition of the output growth rate. This decomposition identifies the contribution of the neutral and IS technology shocks, the two financial shocks, and the other shocks to the growth rate in each period. This figure shows that the neutral technology shock explains most of the movements in the output growth rate, in line with the variance decomposition of output growth. Particularly, an adverse neutral technology shock accounts for most of the fall in output growth during the Great Stagnation in the 1990s. Therefore, our empirical result supports the view of Hayashi and Prescott (2002), who argue that a sharp decline in the growth rate of TFP is the main cause of the Great Stagnation in the 1990s.

To understand the results of the variance and historical decompositions of output growth, impulse responses to the neutral technology shock and the two financial shocks are investigated. Table 4 shows the impulse responses to one standard deviation innovations to shocks to the rate of neutral technological change, the EF premium, and net worth. The positive neutral technology shock increases output growth (100Δ log $Y_t$), consumption growth (100Δ log $C_t$), investment growth (100Δ log $I_t$), labor (100 log $h_t$), real wage growth (100Δ log $W_t$), the monetary policy rate (100 log $r^m_t$), the loan rate (100 log $r^l_t$), and real loan growth (100Δ log $L_t$) and decreases the consumption price inflation rate (100Δ log $P_t$), and thus generates the observed comovement of these variables. The negative EF premium shock and the positive net worth shock also raise output growth, but the EF premium shock reduces consumption growth and the loan rate and increases the consumption price inflation rate, while the net worth shock decreases consumption growth and real loan growth. Therefore, to replicate the observed co-movement of output growth with other observable variables, the neutral technology shock needs to play a substantial role in the model. Consequently, fluctuations in output growth is mainly
4.3 What does the estimated neutral technology shock represent?

This subsection examines our second question of what our estimated neutral technology shock—
which is the main source of Japan’s business cycle fluctuations—really represents. Allegedly
Japan’s Great Stagnation is caused by the dysfunction of the financial system that stemmed
from the collapse of asset price bubbles in the early 1990s. Thus, from this point of view, we
consider the interpretation of the estimated neutral technology shock.

Fig. 2 plots the diffusion index of all enterprises’ financial position (all industries) in the
Tankan, the Short-term Economic Survey of Enterprises in Japan and the estimated rate of
neutral technological change on a year-on-year basis. In this figure, it is evident that these
two time series are strongly correlated (the correlation coefficient is 0.86). Thus, the adverse
neutral technology shock measured during the Great Recession in the 1990s can be considered
to capture a tightening of firms’ financing that induced reduction of R&D investment and
misallocation of capital at that time. In this regard, Ogawa (2007) analyzes a panel dataset
to show that massive amounts of outstanding debt caused declines in firms’ R&D investment
and hence TFP growth during the Great Stagnation in the 1990s. Nishimura et al. (2005) and
Fukao and Kwon (2006) empirically demonstrate that misallocation of resources to inefficient
existing firms is the cause of the slowdown in TFP growth during the Great Stagnation in the
1990s. Behind the background of this TFP slowdown, there is the so-called “evergreening”
behavior of troubled Japanese banks of that time pointed out by Peek and Rosengren (2005)
and Caballero et al. (2008). These authors show that the troubled Japanese banks had an
incentive to allocate credit to severely impaired borrowers (the so-called “zombies”) so as to
avoid the realization of losses on their own balance sheets and this induced misallocation of
credit during the Great Stagnation in the 1990s.

From the results presented in this subsection and the previous one, we argue that an adverse
neutral technology shock which is likely to represent a tightening of firms’ financing that induced
reduction of R&D investment and misallocation of capital caused the Great Stagnation in the
1990s.

10 As a source of fluctuations in TFP growth, Moll (2012) indicates a financial friction that induces misallocation
of capital.
5 Concluding remarks

To fill the gap between Hayashi and Prescott (2002)’s argument and the widespread belief regarding the cause of Japan’s Great Stagnation in the 1990s, the present paper has addressed the questions of what shock is the main cause of the Great Stagnation and what that shock really represents, using an estimated DSGE model augmented with the financial accelerator mechanism of Bernanke et al. (1999) and associated financial shocks to the EF premium and entrepreneurs’ net worth. The estimation results have shown that even in the presence of the financial shocks an adverse neutral technology shock mainly induced the Great Stagnation in the 1990s and that the time series of the estimated rate of neutral technological change is strongly correlated with that of the diffusion index of all enterprises’ financial position in the Tankan, the Short-term Economic Survey of Enterprises in Japan. Based on these findings, we have argued that an adverse neutral technology shock which is likely to represent a tightening of firms’ financing that induced reduction of R&D investment and misallocation of capital caused the Great Stagnation in the 1990s.

This paper shows a relationship between neutral technological change and firms’ financing in Japan. One direction of future research would be thus to endogenize neutral technological change through R&D investment along the lines of Comin and Gertler (2006) and to introduce financial frictions and associated financial shocks in the R&D investment. The estimation of the model with this feature will more directly and more fruitfully fill the gap between Hayashi and Prescott (2002)’s argument and the widespread belief regarding the cause of Japan’s Great Stagnation in the 1990s.

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11 Comin (2011) uses the model of Comin and Gertler (2006) to argue that during the Great Stagnation in the 1990s, firms’ reduction of R&D investment propagated shocks hitting Japan’s economy and made the effects of the shocks very long-lasting. Queraltó (2013) develops a small open economy model with financial frictions in R&D investment and shows that this model can generate highly persistent adverse effects of financial crises on growth of TFP and output as observed in emerging market economies.
Appendix

This appendix presents log-linearized equilibrium conditions and steady-state conditions for estimation. The log-linearized equilibrium conditions used in estimation are given by

\[
\dot{\lambda}_t = -\frac{1}{1 - \beta \theta (z^*)^{-\sigma}} \left\{ \frac{\sigma}{1 - \theta / z^*} \left[ \hat{e}_t - \frac{\theta}{z^*} \left( \hat{\alpha}_{t-1} - z_t^* \right) \right] - z_t^b \right\} + \frac{\beta \theta (z^*)^{-\sigma}}{1 - \beta \theta (z^*)^{-\sigma}} \left[ \frac{\sigma}{1 - \theta / z^*} \left( E_t \hat{\alpha}_{t+1} + E_t z_{t+1}^* - \frac{\theta}{z^*} \hat{e}_t \right) - E_t z_{t+1}^b \right],
\]

\[
\dot{\lambda}_t = E_t \dot{\lambda}_{t+1} - \sigma E_t z_{t+1}^* + \dot{r}_t^\pi - E_t \dot{\pi}_{t+1},
\]

\[
\dot{w}_t = \hat{w}_{t-1} - \hat{\pi}_t + \gamma_w \hat{\pi}_{t-1} - z_t^* + \beta (z^*)^{1-\sigma} \left( E_t \hat{w}_{t+1} - \hat{w}_t + E_t \hat{\pi}_{t+1} - \gamma_w \hat{\pi}_t + E_t z_{t+1}^* \right)
\]

\[
\quad \quad \quad + \frac{(1 - \xi_w)(1 - \beta (z^*)^{1-\sigma} \xi_w)}{\xi_w (1 + \chi (1 + \lambda^w) / \lambda^w)} \left( \chi \hat{h}_t - \hat{\lambda}_t - \hat{w}_t + z_t^b \right) + z_t^w,
\]

\[
\hat{t}_t = \frac{1 + \lambda^i}{1 + \lambda^i - n / k} \left( \hat{q}_t + \hat{k}_t \right) + \left( 1 - \frac{1 + \lambda^i}{1 + \lambda^i - n / k} \right) \hat{n}_t,
\]

\[
E_t \hat{x}_{t+1} = \hat{r}_t^l - E_t \hat{\pi}_{t+1},
\]

\[
\hat{x}_t = \left( 1 - \frac{1 - \delta}{r^l \psi / \pi} \right) \hat{r}_t^l + \frac{1 - \delta}{r^l \psi / \pi} \hat{q}_t - \hat{q}_{t-1} - z_t^\psi,
\]

\[
\hat{r}_t^l = \hat{r}_t^\pi + \mu \left( \hat{q}_t + \hat{k}_t - \hat{n}_t \right) + z_t^\pi,
\]

\[
\hat{n}_t = \frac{\eta^l}{z^* \pi} \left[ \frac{1 + \lambda^i}{n / k} \hat{x}_t - \left( \frac{1 + \lambda^i}{n / k} - 1 \right) \left( \hat{r}_{t-1} - \hat{\pi}_t \right) + \hat{n}_{t-1} - z_t^* \right] + z_t^\pi,
\]

\[
0 = \hat{w}_t - \hat{h}_t - \left( \hat{r}_t^k + \hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi \right),
\]

\[
\hat{u}_t = \tau \left( \hat{r}_t^k - \hat{q}_t \right),
\]

\[
m_c_t = (1 - \alpha) \hat{w}_t + \alpha \hat{r}_t^k,
\]

\[
\hat{\pi}_t = \gamma_p \hat{\pi}_{t-1} + \beta (z^*)^{1-\sigma} \left( E_t \hat{\pi}_{t+1} - \gamma_p \hat{\pi}_t \right) + \frac{(1 - \xi_p)(1 - \beta (z^*)^{1-\sigma} \xi_p)}{\xi_p} \hat{m}_c_t + z_t^p,
\]

\[
\hat{y}_t = (1 + \phi) \left[ (1 - \alpha) \hat{h}_t + \alpha \left( \hat{u}_t + \hat{k}_{t-1} - z_t^* - z_t^\psi \right) \right],
\]

\[
\hat{y}_t = \frac{c}{y} \hat{e}_t + \frac{i}{y} \hat{n}_t + z_t^\theta,
\]

\[
\hat{k}_t = \frac{1 - \delta - r^E \psi}{z^* \psi} \hat{u}_t + \frac{1 - \delta}{z^* \psi} \left( \hat{k}_{t-1} - z_t^* - z_t^\psi \right) + \left( 1 - \frac{1 - \delta}{z^* \psi} \right) \left( \hat{t}_t + z_t^\psi \right),
\]

\[
\hat{q}_t = \zeta \left( \hat{t}_t - \hat{q}_{t-1} + z_t^* + z_t^\psi \right) - \beta (z^*)^{1-\sigma} \zeta \left( E_t \hat{q}_{t+1} - \hat{q}_t + E_t z_{t+1}^* + E_t z_{t+1}^\psi \right) - z_t^\theta + z_t^\pi.
\]

\[
\hat{r}_t^\pi = \phi_r \hat{r}_{t-1}^\pi + (1 - \phi_r) \left( \frac{\phi_r}{4} \sum_{j=0}^{3} \hat{\pi}_{t-j} + \phi \hat{q}_t \right) + \phi \Delta g (\hat{y}_t - \hat{y}_{t-1} + z_t^* + z_t^\pi) + z_t^\pi,
\]

where hatted variables represent log-deviations from steady-state values and \( z_t^\psi = z_t^* + \alpha / (1 - \alpha) z_t^\psi \) is the composite technology shock.
The steady-state conditions used in estimation are given by

\[
\beta = \frac{(z^*)^\sigma \pi}{r^u}, \quad r^k = \frac{1 + \lambda^l \psi}{u^l} \left[ \frac{r^l \psi}{\pi} - (1 - \delta) \right], \quad \lambda^p = \phi, \quad w = (1 - \alpha) \left[ \frac{1}{1 + \lambda^p} \left( \frac{\alpha}{r^k} \right)^\alpha \right]^{\frac{1}{1-\alpha}},
\]

\[
\frac{h}{k} = \frac{1 - \alpha}{\alpha} \frac{u}{z^* \psi} \frac{r^k}{w}, \quad \frac{k}{y} = (1 + \phi) \left( \frac{z^* \psi}{u} \right)^\alpha \left( \frac{h}{k} \right)^{\alpha - 1}, \quad \frac{i}{k} = 1 - \frac{1 - \delta}{z^* \psi}, \quad \frac{i}{y} = \frac{i}{k} \frac{k}{y}, \quad \frac{c}{y} = 1 - \frac{g}{y} - \frac{i}{y}.
\]
References


Table 1: Prior and posterior distributions of parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Prior Type</th>
<th>Mean</th>
<th>S.D.</th>
<th>Mean</th>
<th>S.D.</th>
<th>90% interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma ) Risk aversion</td>
<td>G</td>
<td>1.000</td>
<td>0.375</td>
<td>1.992</td>
<td>1.417</td>
<td>[2.543]</td>
</tr>
<tr>
<td>( \theta ) Habit persistence</td>
<td>B</td>
<td>0.700</td>
<td>0.150</td>
<td>0.258</td>
<td>0.158</td>
<td>[0.348]</td>
</tr>
<tr>
<td>( \chi ) Inverse of elasticity of labor supply</td>
<td>G</td>
<td>2.000</td>
<td>0.750</td>
<td>4.126</td>
<td>2.531</td>
<td>[5.630]</td>
</tr>
<tr>
<td>( \zeta ) Elasticity of investment adjustment cost</td>
<td>G</td>
<td>4.000</td>
<td>1.500</td>
<td>4.252</td>
<td>0.225</td>
<td>[6.633]</td>
</tr>
<tr>
<td>( \tau ) Inverse of elasticity of utilization rate adjustment cost</td>
<td>G</td>
<td>0.220</td>
<td>0.100</td>
<td>0.475</td>
<td>0.305</td>
<td>[0.632]</td>
</tr>
<tr>
<td>( \phi ) Output share of fixed production cost</td>
<td>B</td>
<td>0.075</td>
<td>0.013</td>
<td>0.080</td>
<td>0.059</td>
<td>[0.102]</td>
</tr>
<tr>
<td>( \alpha ) Capital elasticity of output</td>
<td>B</td>
<td>0.300</td>
<td>0.050</td>
<td>0.161</td>
<td>0.131</td>
<td>[0.190]</td>
</tr>
<tr>
<td>( \gamma_w ) Wage indexation</td>
<td>B</td>
<td>0.500</td>
<td>0.250</td>
<td>0.497</td>
<td>0.113</td>
<td>[0.882]</td>
</tr>
<tr>
<td>( \xi_w ) Wage stickiness</td>
<td>B</td>
<td>0.375</td>
<td>0.100</td>
<td>0.503</td>
<td>0.395</td>
<td>[0.620]</td>
</tr>
<tr>
<td>( \gamma_p ) Intermediate-good price indexation</td>
<td>B</td>
<td>0.500</td>
<td>0.250</td>
<td>0.408</td>
<td>0.074</td>
<td>[0.720]</td>
</tr>
<tr>
<td>( \xi_p ) Intermediate-good price stickiness</td>
<td>B</td>
<td>0.375</td>
<td>0.100</td>
<td>0.675</td>
<td>0.619</td>
<td>[0.731]</td>
</tr>
<tr>
<td>( \phi_p ) Monetary policy rate smoothing</td>
<td>B</td>
<td>0.800</td>
<td>0.100</td>
<td>0.749</td>
<td>0.674</td>
<td>[0.824]</td>
</tr>
<tr>
<td>( \phi_r ) Monetary policy response to inflation</td>
<td>G</td>
<td>1.700</td>
<td>0.100</td>
<td>1.652</td>
<td>1.508</td>
<td>[1.794]</td>
</tr>
<tr>
<td>( \phi_y ) Monetary policy response to output</td>
<td>G</td>
<td>0.125</td>
<td>0.050</td>
<td>0.117</td>
<td>0.058</td>
<td>[0.175]</td>
</tr>
<tr>
<td>( \phi_{ay} ) Monetary policy response to output growth</td>
<td>G</td>
<td>0.125</td>
<td>0.050</td>
<td>0.054</td>
<td>0.030</td>
<td>[0.078]</td>
</tr>
<tr>
<td>( \eta ) Entrepreneur survival probability</td>
<td>B</td>
<td>0.973</td>
<td>0.020</td>
<td>0.992</td>
<td>0.984</td>
<td>[0.999]</td>
</tr>
<tr>
<td>( n/k ) Steady-state net worth-capital ratio</td>
<td>B</td>
<td>0.500</td>
<td>0.070</td>
<td>0.456</td>
<td>0.377</td>
<td>[0.538]</td>
</tr>
<tr>
<td>( \mu ) Elasticity of EF premium</td>
<td>G</td>
<td>0.038</td>
<td>0.019</td>
<td>0.006</td>
<td>0.003</td>
<td>[0.009]</td>
</tr>
<tr>
<td>( \xi^B ) Steady-state rate of balanced growth</td>
<td>G</td>
<td>0.370</td>
<td>0.100</td>
<td>0.387</td>
<td>0.250</td>
<td>[0.521]</td>
</tr>
<tr>
<td>( \psi ) Steady-state rate of IS technological change</td>
<td>G</td>
<td>0.460</td>
<td>0.100</td>
<td>0.389</td>
<td>0.259</td>
<td>[0.516]</td>
</tr>
<tr>
<td>( \bar{n} ) Normalized steady-state hours worked</td>
<td>N</td>
<td>0.000</td>
<td>2.000</td>
<td>0.253</td>
<td>-2.386</td>
<td>[2.686]</td>
</tr>
<tr>
<td>( \pi ) Steady-state inflation rate</td>
<td>G</td>
<td>0.340</td>
<td>0.100</td>
<td>0.559</td>
<td>0.365</td>
<td>[0.749]</td>
</tr>
<tr>
<td>( \bar{\tau} ) Steady-state policy rate</td>
<td>G</td>
<td>1.090</td>
<td>0.100</td>
<td>1.109</td>
<td>0.968</td>
<td>[1.255]</td>
</tr>
<tr>
<td>( \bar{\tau}^L ) Steady-state loan rate</td>
<td>G</td>
<td>1.490</td>
<td>0.100</td>
<td>1.343</td>
<td>1.204</td>
<td>[1.484]</td>
</tr>
<tr>
<td>( \rho_b ) Persistence of preference shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.858</td>
<td>0.717</td>
<td>[0.977]</td>
</tr>
<tr>
<td>( \rho_g ) Persistence of exogenous demand shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.991</td>
<td>0.983</td>
<td>[0.999]</td>
</tr>
<tr>
<td>( \rho_w ) Persistence of wage shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.308</td>
<td>0.089</td>
<td>[0.518]</td>
</tr>
<tr>
<td>( \rho_p ) Persistence of intermediate-good price markup shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.976</td>
<td>0.956</td>
<td>[0.997]</td>
</tr>
<tr>
<td>( \rho_i ) Persistence of investment-good price markup shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.929</td>
<td>0.878</td>
<td>[0.981]</td>
</tr>
<tr>
<td>( \rho_r ) Persistence of monetary policy shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.366</td>
<td>0.193</td>
<td>[0.535]</td>
</tr>
<tr>
<td>( \rho_z ) Persistence of neutral technology shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.051</td>
<td>0.008</td>
<td>[0.094]</td>
</tr>
<tr>
<td>( \rho_{\psi} ) Persistence of IS technology shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.981</td>
<td>0.966</td>
<td>[0.997]</td>
</tr>
<tr>
<td>( \rho_{\nu} ) Persistence of MEI shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.999</td>
<td>0.998</td>
<td>[0.999]</td>
</tr>
<tr>
<td>( \rho_{\mu} ) Persistence of EF premium shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.892</td>
<td>0.850</td>
<td>[0.936]</td>
</tr>
<tr>
<td>( \rho_n ) Persistence of net worth shock</td>
<td>B</td>
<td>0.500</td>
<td>0.200</td>
<td>0.670</td>
<td>0.547</td>
<td>[0.792]</td>
</tr>
<tr>
<td>( \sigma_{b} ) S.D. of preference shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>2.558</td>
<td>1.794</td>
<td>[3.296]</td>
</tr>
<tr>
<td>( \sigma_{g} ) S.D. of exogenous demand shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.517</td>
<td>0.447</td>
<td>[0.585]</td>
</tr>
<tr>
<td>( \sigma_{w} ) S.D. of wage shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.543</td>
<td>0.423</td>
<td>[0.660]</td>
</tr>
<tr>
<td>( \sigma_{p} ) S.D. of intermediate-good price markup shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.165</td>
<td>0.103</td>
<td>[0.226]</td>
</tr>
<tr>
<td>( \sigma_{i} ) S.D. of investment-good price markup shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.413</td>
<td>0.340</td>
<td>[0.487]</td>
</tr>
<tr>
<td>( \sigma_{r} ) S.D. of monetary policy shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.138</td>
<td>0.116</td>
<td>[0.159]</td>
</tr>
<tr>
<td>( \sigma_{z} ) S.D. of neutral technology shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>1.291</td>
<td>1.101</td>
<td>[1.468]</td>
</tr>
<tr>
<td>( \sigma_{\psi} ) S.D. of IS technology shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.135</td>
<td>0.105</td>
<td>[0.164]</td>
</tr>
<tr>
<td>( \sigma_{\nu} ) S.D. of MEI shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>3.768</td>
<td>3.047</td>
<td>[4.478]</td>
</tr>
<tr>
<td>( \sigma_{\mu} ) S.D. of EF premium shock innovation</td>
<td>IG</td>
<td>0.500</td>
<td>Inf</td>
<td>0.116</td>
<td>0.100</td>
<td>[0.132]</td>
</tr>
<tr>
<td>( \sigma_{\eta} ) S.D. of net worth shock innovation</td>
<td>25</td>
<td>0.500</td>
<td>Inf</td>
<td>1.390</td>
<td>0.952</td>
<td>[1.803]</td>
</tr>
</tbody>
</table>

Note: In the type of prior distributions, B, G, IG, and N stand for Beta, Gamma, Inverse Gamma, and Normal distributions, respectively.
Table 2: Cross-correlations in the data and the model.

<table>
<thead>
<tr>
<th>Variable ((x))</th>
<th>Cross-correlation of output growth (\Delta \log Y_t) with:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(x(-5))</td>
</tr>
<tr>
<td>(\Delta \log Y_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log C_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log I_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\log h_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log W_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log P_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log(P_t^i/P_t))</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\log r_t^n)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\log r_t^l)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log L_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
<tr>
<td>(\Delta \log N_t)</td>
<td>Data</td>
</tr>
<tr>
<td></td>
<td>Model</td>
</tr>
</tbody>
</table>

Note: This table shows the cross-correlations of output growth \((\Delta \log Y_t)\) with all the eleven observable variables in the data and in the model evaluated at the posterior mean estimates of parameters.
Table 3: Variance decompositions.

<table>
<thead>
<tr>
<th>Shock</th>
<th>$\Delta \log Y_t$</th>
<th>$\Delta \log C_t$</th>
<th>$\Delta \log I_t$</th>
<th>$\log h_t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$z^p$ Preference</td>
<td>5.4</td>
<td>26.0</td>
<td>9.5</td>
<td>8.2</td>
</tr>
<tr>
<td>$z^g$ Exogenous demand</td>
<td>0.4</td>
<td>7.1</td>
<td>0.6</td>
<td>1.2</td>
</tr>
<tr>
<td>$z^w$ Wage</td>
<td>6.1</td>
<td>1.5</td>
<td>8.5</td>
<td>16.9</td>
</tr>
<tr>
<td>$z^p$ Intermediate-good price markup</td>
<td>11.2</td>
<td>2.0</td>
<td>17.0</td>
<td>26.4</td>
</tr>
<tr>
<td>$z^i$ Investment-good price markup</td>
<td>0.2</td>
<td>0.2</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>$z^r$ Monetary policy</td>
<td>4.5</td>
<td>1.2</td>
<td>6.4</td>
<td>8.6</td>
</tr>
<tr>
<td>$z^z$ Neutral technology</td>
<td>66.2</td>
<td>48.6</td>
<td>23.2</td>
<td>25.8</td>
</tr>
<tr>
<td>$z^\psi$ IS technology</td>
<td>2.3</td>
<td>10.4</td>
<td>21.3</td>
<td>7.2</td>
</tr>
<tr>
<td>$z^\nu$ MEI</td>
<td>1.9</td>
<td>0.5</td>
<td>2.5</td>
<td>0.8</td>
</tr>
<tr>
<td>$z^\mu$ EF premium</td>
<td>1.6</td>
<td>1.8</td>
<td>8.5</td>
<td>4.0</td>
</tr>
<tr>
<td>$z^\eta$ Net worth</td>
<td>0.2</td>
<td>0.9</td>
<td>1.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Note: This table shows the variance decomposition of output growth ($\Delta \log Y_t$), consumption growth ($\Delta \log C_t$), investment growth ($\Delta \log I_t$), and labor ($\log h_t$) corresponding to periodic components with frequency between 8 and 32 quarters, evaluated at the posterior mean estimates of parameters.
Table 4: Impulse responses to the neutral technology shock, the EF premium shock, and the net worth shock.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Neutral technology shock $z_t^T (+1 \text{ s.d.})$</th>
<th>EF premium shock $z_t^P (-1 \text{ s.d.})$</th>
<th>Net worth shock $z_t^N (+1 \text{ s.d.})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$t = 1$</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>$100\Delta \log Y_t$</td>
<td>1.11</td>
<td>0.38</td>
<td>0.19</td>
</tr>
<tr>
<td>$100\Delta \log C_t$</td>
<td>0.90</td>
<td>0.28</td>
<td>0.09</td>
</tr>
<tr>
<td>$100\Delta \log I_t$</td>
<td>1.78</td>
<td>1.65</td>
<td>1.16</td>
</tr>
<tr>
<td>$100\log h_t$</td>
<td>0.03</td>
<td>0.35</td>
<td>0.52</td>
</tr>
<tr>
<td>$100\Delta \log W_t$</td>
<td>0.44</td>
<td>0.30</td>
<td>0.21</td>
</tr>
<tr>
<td>$100\Delta \log P_t$</td>
<td>-0.17</td>
<td>-0.13</td>
<td>-0.06</td>
</tr>
<tr>
<td>$100\Delta \log(P_t^I/P_t)$</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>$100\log r_t^n$</td>
<td>0.04</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>$100\log r_t^l$</td>
<td>0.04</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>$100\Delta \log L_t$</td>
<td>0.21</td>
<td>0.26</td>
<td>0.19</td>
</tr>
<tr>
<td>$100\Delta \log N_t$</td>
<td>-0.10</td>
<td>0.18</td>
<td>0.08</td>
</tr>
</tbody>
</table>

Note: This table shows the impulse responses of all the eleven observable variables to one standard deviation innovations to the neutral technology shock, the EF premium shock, and the net worth shock, evaluated at the posterior mean estimates of parameters.
Figure 1: Historical decomposition of the output growth rate.

Note: This figure shows the historical decomposition of the output growth rate based on the posterior mean estimates of parameters and the Kalman smoothed mean estimates of shocks.
Figure 2: The diffusion index of all enterprises’ financial position in the Tankan and the estimated rate of neutral technological change

Note: This figure compares the time series of the diffusion index of all enterprises’ financial position (all industries) in the Tankan, the Short Economic Survey of Enterprises in Japan and that of the estimated rate of neutral technological change on a year-on-year basis.